

MATERIAL-DEPENDENT ELECTRIC FIELD
ENHANCEMENT OF PHOTOCONDUCTIVITY IN GALLIUM ARSENIDE

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ABSTRACT

Pulsed laser measurements on as-grown and thermally processed gallium arsenide show a material dependent photoconductivity. The pulsed voltage measurements on as-grown material provide evidence of a gain mechanism. An understanding of the photocurrent gain on the nature of the bulk gallium arsenide may be useful in explaining the lock-on phenomenon and in designing high power GaAs photoconductive devices.

INTRODUCTION

We report evidence of a material dependent electric field enhancement of photoconductivity in semi-insulating GaAs switches. We see a material dependent photoconductive efficiency from pulsed laser measurements on as-grown and thermally processed material. The as-grown material exhibits an unexpected linear increase in photocurrent in the regime where the carrier velocity is known to be saturated¹, whereas the thermally processed material showed a decrease in photocurrent at higher electric fields in all cases. Additional measurements of the as-grown material supported the linear photocurrent increase. These photocurrent measurements included both pulsed Nd:YAG laser exposure and cw LED illumination on samples biased with varying pulse widths and voltages.

CW LED ILLUMINATION

Transient photocurrent measurements under high voltage pulse bias were made with the sample exposed to continuous infrared illumination from a GaAs LED diode in the milliwatt range. The net photocurrent in which the dark current was subtracted from the transient photocurrent was studied as a function of time and electric field. The center wavelength of the LED was 0.905 microns corresponding to a photon energy of 1.37 eV which is on the band edge of GaAs.

The circuit for these measurements is shown in Figure 1. The Cober pulse generator provided the voltage pulses of varying amplitude and width. The transient photocurrent was measured across the 3.9 k Ω . In all cases the resistance of the GaAs sample was no less than 850 k Ω , much greater than the other circuit resistances. Sample voltages were measured by a Tektronix P6009 100X probe.

The test samples were fabricated from a wafer of undoped, EL2 compensated, semi-insulating GaAs purchased from MA/COM. The GaAs was degreased, cleaned and etched and then metallized by e-beam deposition. The 2 mm thick wafer was cut into 4 mm X 4 mm squares, etched to remove excess metal and then the contacts deposited using the Au/Ge/Ni/Ag metallization scheme. Finished devices were 4 mm X 4 mm square by 2 mm thick. The two electrodes covered both surfaces completely leaving only the sides of the devices to provide the electrical isolation.

Transient photocurrents were measured in response to fast rise pulses of 400, 800, 1200 and 2000 volt amplitudes. Pulse widths varied from 100 to 700 ns. Photos of the resulting current waveforms were photographed showing both the illuminated and dark currents

for each of the voltages and pulse widths. Figure 2 shows the results for a 2000 volt pulse 700 ns wide. The net photocurrent measured at the end of each voltage pulse width is plotted in Figure 3 for three of the four voltages. The curves of photocurrent with time show an initial rise until 300 ns after which the photocurrent reaches a steady state. The same data plotted as photocurrent vs. electric field in Figure 4. The family of curves are for net photocurrent taken sometime after the beginning of the voltage pulse. It is clear in the I-V plots that the net photocurrents are almost linear with electric field for times greater than 200 ns.

A computer simulation was performed to ensure that the measurements are not dominated by simple dielectric relaxation effects. The results of the simulation are shown in Figure 5. The device in the test circuit was modeled as a "leaky capacitor" with a capacitor in parallel with a field dependent resistor based on the circuit shown in Figure 6. The capacitance value used in the simulation was the parallel plate capacitance of the sample. The low field leakage resistance was obtained from the net photocurrent under 400 volts and 700 ns into the pulse. The leakage resistance increased beyond this value linearly with electric field as the device was operated in the saturated carrier velocity regime². A comparison of Figures 4 and 5 demonstrate that simple dielectric relaxation cannot explain the observed results. The actual experimental results show an almost linear increase in net photoconductivity as a function of electric field whereas the simulation shows an almost linear decrease. The difference is thought to be due to a gain mechanism.

PULSED LASER MEASUREMENTS

In the pulsed laser study we examined the effect of electric field on peak photocurrent under low intensity illumination and high voltage bias using GaAs samples with a controlled range of properties. As-grown, undoped, semi-insulating GaAs as well as GaAs that had undergone the inverted thermal conversion process (ITC) developed by Lagowski. This remarkable processing technique controls the concentration and occupancy fraction of the EL2 deep level which is known to affect resistivity^{3, 4}. The devices used in this study were fabricated similar to the previous mentioned devices except for size. In this study the devices were 4 mm X 4 mm X 1 mm thick with 2 mm diameter round contacts on opposite sides. The laser was a Quantel YG-370 Q-switched Nd:YAG 4 ns FWHM 200 mJ, 1.06 μ pulse. The laser pulse was attenuated so that 50 μ J reached the sample. Optical pulses were monitored by a Scientech 365 power/energy meter and checked with an EG&G FND100 photodiode. Bias voltage was varied from 50 to 900 volts in 50 volt increments using the Cover pulser to charge the 25 Ω , 200 ns coaxial PFL through a 5 k Ω charging resistor. The transient current was monitored by a Tektronix CT-1 current transformer supplemented by a 50 Ω current viewing resistor. The measurements were taken on a Tektronix 7104 oscilloscope with both a 7A29 and 7A26 plug-ins. A Tektronix C1001 video camera captured each trace which was digitized in a Zenith micro-computer using DGS version 2.0 software. A schematic of the circuit for pulsed laser measurements is shown

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in Figure 7. A plot of peak current versus electric field for a variety of samples is shown in Figure 8. All the measurements were taken with the laser illumination held constant. The peak currents followed the peak laser intensity very closely with each point in the curve representing an average of 10 measurements taken at 10 Hz. Thermal effects were ruled out by taking similar data single shot. The results show that all of the thermally treated materials show a significant decrease in peak current as the electric field is increased about 4 kV/cm (saturated carrier velocity regime). The as-grown samples do not follow the same trend and only decrease slightly from its peak value at 7.5 kV/cm. This is the same material used in the previously reported as LED studies.

CONCLUSIONS

As-grown GaAs, undoped, semi-insulating samples were compared to samples prepared from the same material that had undergone the inverted thermal conversion process (ITC) developed by Lagowski. There is evidence of a material dependent electric field enhancement of photoconductivity in semi-insulating GaAs devices. This effect cannot be explained by simple dielectric relaxation.

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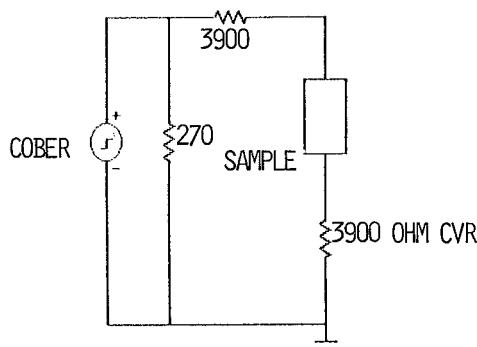


FIGURE 1. THE CIRCUIT FOR MEASURING PHOTOCURRENT UNDER HIGH VOLTAGE PULSE CONDITIONS.

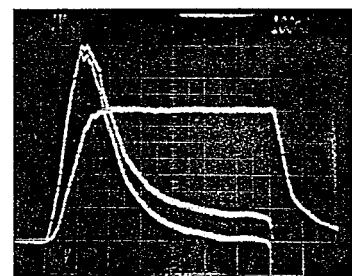


FIGURE 2. PHOTO OF TRANSIENT PHOTOCURRENT FOR A 2000 VOLT, 700 NS WIDE PULSE.

NET PHOTOCURRENT VS TIME

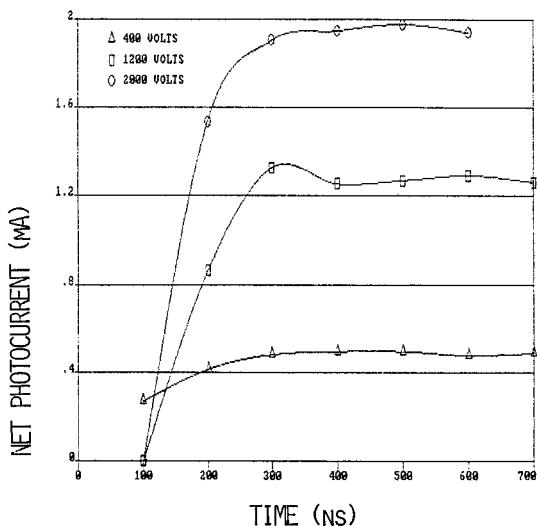


FIGURE 3. PLOTS OF NET PHOTOCURRENT AT THE END OF THE PULSE FOR VARYING PULSE WIDTHS.

NET PHOTOCURRENT VS VOLTAGE

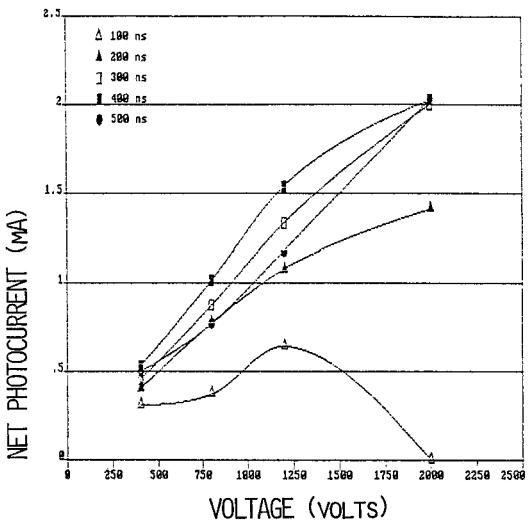


FIGURE 4. THE DATA OF FIGURE 3 PLOTTED AS PHOTOCURRENT VS. ELECTRIC FIELD.

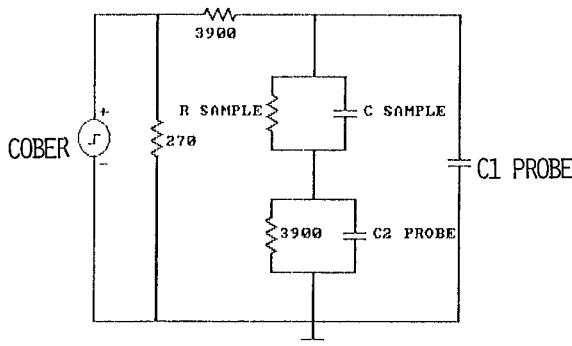


FIGURE 5. THE RESULTS FROM THE SIMULATION FOR NET PHOTOCURRENT AT THE END OF THE PULSE FOR VARYING PULSE WIDTHS VERSUS PULSE VOLTAGE.

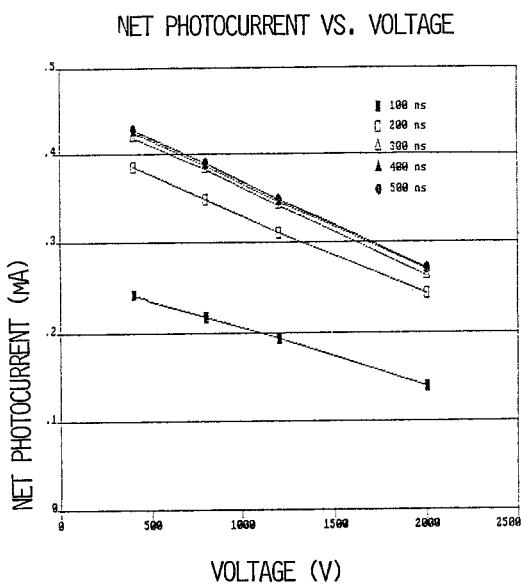


FIGURE 6. THE CIRCUIT USED TO SIMULATE DIELECTRIC RELAXATION EFFECTS IN THE MEASUREMENT CIRCUIT.

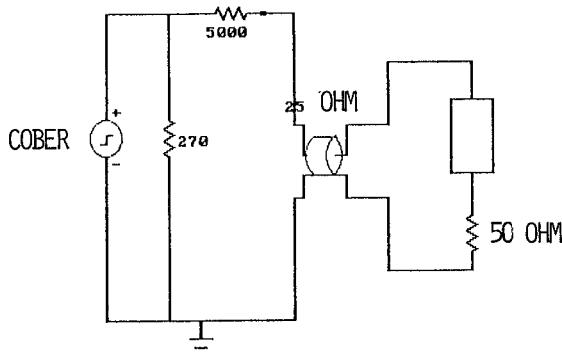


FIGURE 7. A SCHEMATIC OF THE CIRCUIT FOR PULSED LASER MEASUREMENTS.

PEAK PHOTOCURRENT VS. ELECTRIC FIELD

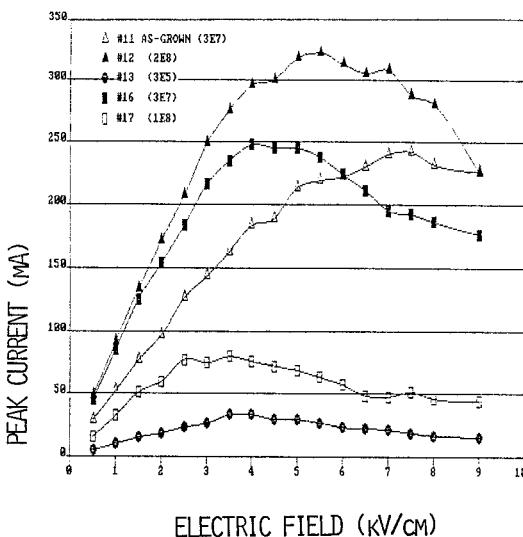


FIGURE 8. A PLOT OF PEAK CURRENT VERSUS ELECTRIC FIELD FOR A VARIETY OF GaAs SAMPLES WITH VARYING E_{L2} CONCENTRATIONS UNDER PULSED LASER ILLUMINATION.